

Seeing the world around you involves more than just opening your eyes. Although perception often seems effortless, the process by which the brain converts patterns of light into an understanding of objects is truly astounding, and even today only incompletely understood.

From its title onward, Donald Hoffman's book *Visual Intelligence* (1998) captures one of the most important yet often underappreciated aspects of vision: that it is not just about perceiving brightness and color, it is about using your brain to make supremely educated guesses about what's out there in the world. Any digital camera can sharpen an image, but it takes a human being (or at least a very clever animal) to *understand* what it is seeing. By probing the nature of our visual intelligence—and describing what he calls “vision by construction”—Hoffman cuts to the core of one of our most powerful senses.

In a selection from his book *Sensory Exotica* (1999), Howard C. Hughes reminds us that our five familiar senses—hearing, seeing, smelling, tasting, and touching—are not the only senses found in the animal world. Describing a panoply of senses that we as humans don't have (or have in only limited ways), such as echolocation, navigation by internal compass, and even “electroreception,” Hughes uses the perceptions of other creatures to bring our own world view into sharper relief.

## From Visual Intelligence: How We Create What We See

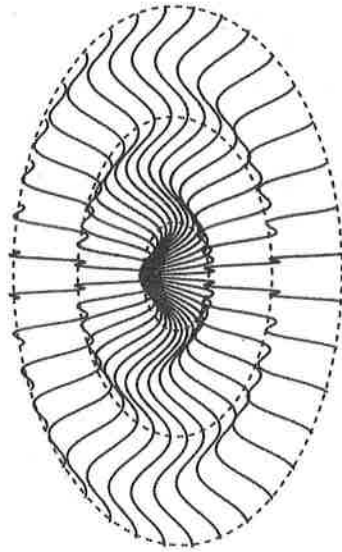
Donald D. Hoffman

You are a creative genius. Your creative genius is so accomplished that it appears, to you and to others, as effortless. Yet it far outstrips the most valiant efforts of today's fastest supercomputers. To invoke it, you need only open your eyes. This might sound like the mantra of a new therapy, or the babble of a fortune cookie. But it is, instead, the reasoned conclusion of researchers in the field of cognitive science. What happens when you see is not a mindless process of stimulus and response, as behaviorists thought for much of the twentieth century, but a sophisticated process of construction whose intricacies we are now beginning to understand. In a fraction of a second your visual intelligence can construct the strut and colors of a peacock, or the graceful run of a leopard, or the fireworks of an ocean sunset, or the nuances of light in a forest at dusk, or any of countless other scenes of such subtlety and complexity. In repertoire and speed you far surpass the greatest of painters.

You are a visual virtuoso. Perhaps, though, you are unaware of or flatly disbelieve in your innate talent. My goal is to persuade you otherwise, to present you with the evidence uncovered by researchers in the cognitive sciences, evidence that, quite frankly, has come as a surprise to the researchers themselves. Indeed, rumor has it, an early researcher at MIT so underestimated vision that he assigned it to a graduate student as a summer project, a mere warm-up for more substantial forays into human and artificial intelligence. Now, a few decades later, thousands of researchers in a variety of disciplines work full-time to explore the genius of vision. What they have found will, I suspect, prod even the most jaded of viewers to awe.

Your visual prowess is nowhere more impressive than when you view a natural scene. But to appreciate that prowess it is best to begin with something far simpler. This is, after all, the method of science: study first the

simple, then the complex. Try arithmetic before calculus. In this spirit, let's look first at a simple figure, a mere trifle for the constructive powers of your visual intelligence. Here is the "ripple":



This figure is of course a drawing on a flat—or, more precisely, two-dimensional (2D)—surface. You can check this, should you wish to, by touching it. But the figure also appears to be, as the name "ripple" suggests, a surface that is far from flat, and that undulates in space like waves on a pond. You can check this by viewing the figure. Indeed, *try* to see the ripple as flat; I have never succeeded.

Logic dictates that the ripple cannot be at once flat and not flat, so either the hand or the eye (or both) must be in error. Everyone to whom I have shown the ripple has opted to believe the hand. So assume for now that the hand is right and the figure is flat. Then your visual system has made a serious error: it has constructed an elaborate ripple in space despite ample evidence that this construction is unwarranted. And it perseverates in this error, ignoring your better judgment that the figure must be flat. This might not seem the virtuoso performance I mentioned a moment ago.

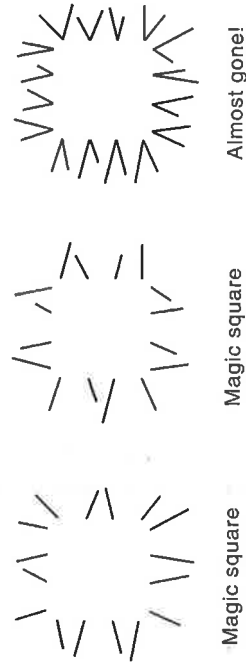
There is, as we shall see, method to this visual madness. But for now, look again at the ripple and note that it has three parts: a bump in the center, a circular wave around the bump, and another circular wave on the outside. As an aid to discuss the figure, I drew dashed curves along the boundaries of these parts.

We have gone from bad to worse. Your visual system not only fabricates the ripple, it then endows it with parts. But could it be that the dashed curves—and not your visual system—are the real culprits here, and that

without the dashed curves you would see no parts? You can check that this is not so. Simply turn the figure, or your head, upside down. You now see an inverted ripple with new parts: the dashed curves now lie on crests of waves and not, as before, in the troughs between waves. Turning the figure upright restores the original parts. And if you turn the figure slowly you can catch it in the act of flipping from one set of parts to the other. So the dashed curves aren't the culprits, since the parts you see in the inverted ripple don't always respect those curves.

Has your visual system gone off the deep end? It constructs from whole cloth a ripple in space and then proceeds to embellish it with mutable parts. Shall we henceforth distrust the witness of vision, knowing now its penchant to perjure?

This last conclusion is of course too hasty. Our evidence, so far, suggests only a single mistake, not inveterate fabrication. To establish the harsher verdict, we must consider more evidence. That we shall do through much of this book. In the process we shall find that your construction of the ripple and its parts follows a beautiful logic. But for now consider next the "magic square":



The middle figure consists of sixteen lines at random orientations. You might see, in addition, four edges that form the boundary of a square. And the square itself might look a brighter white than the rest of the page. But a photometer, a device which measures light intensity by catching and counting light particles, would discern neither the edges nor the brighter interior of this square.

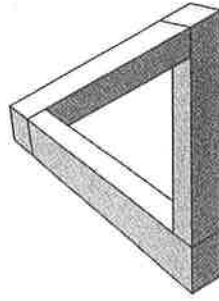
Logic again dictates that the figure cannot at once contain and not contain a bright square, so either the photometer or your visual system (or both) must be in error. Everyone to whom I have shown the magic square

has opted to believe the photometer. So assume for now that the photometer is right and the figure has no bright square. Then your visual system has again made a serious error, and of the same type it did with the ripple: elaborate fabrication.

The magic square appears as well in the figure on the left. But when I superpose the left and middle figures to obtain the figure on the right, the magic square almost disappears. This seems to make no sense. If the left figure and the middle figure each prompt your visual system to construct a square, then we should expect, if anything, that superposing them would prompt your visual system to construct another, more salient, square. After all, there is now twice the "evidence" for a square, since there are now twice as many lines that terminate along its presumed boundary. Why build a square based on small evidence, and yet refuse to build one when there is more? This example, and the ripple, suggest that your visual system not only fabricates, it does so willy-nilly.

This charge is again too hasty. We will find that your visual system fabricates, and does so chronically—but not willy-nilly. There is a compelling logic to your construction, and deconstruction, of the magic square.

Now consider the "devil's triangle," a fiendish figure devised in 1934 by Oscar Reutersvärd:

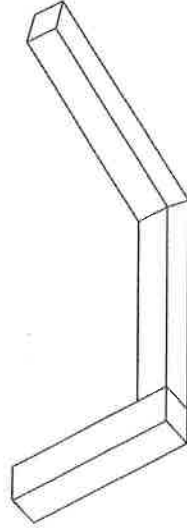


Once again we catch vision in the act of perjury. Its testimony to a solid triangle extended in depth is flatly contradicted by evidence from the hand. But this time we also catch vision in that joy of opposing counsel: self-contradiction. The triangle that is so confidently fabricated by vision, and which vision will not retract despite the witness of the hand, is not consistent. You could not build it with lumber and nails, which is why it's sometimes called the "impossible triangle."

This is striking. It suggests that vision not only fabricates, it does so, at times, unconstrained by reality. Constrained fabrication we might endure,

but fabrication unconstrained goes well beyond the pale. Perhaps, though, the devil's triangle is exceptional. Perhaps the visual system fabricates an inconsistency simply because there is no way, given this figure, to fabricate anything else. If so, we might excuse the visual system on grounds that it must, by nature, fabricate and that no consistent fabrication could be had. This explanation is attractive because it would avoid accusing vision of gratuitous inconsistency, and would confine all inconsistencies to such rarities as psychology labs and exhibitions of Escher.

An admirable try, but it won't work. There are, as it happens, many (infinitely many!) different objects one can build with lumber and nails that, if photographed from the proper angle, give the same image as the devil's triangle. The psychologist Richard Gregory has taken the time to build one. His construction looks something like this:



If you construct this with wood and view it from just the right angle, you can see the devil's triangle. Of course, what you construct with wood is not the devil's triangle itself, since that is impossible. Instead what you construct with wood is another object which, when viewed from the appropriate angle, leads you to see the devil's triangle.

So we can't excuse the visual system on grounds it had no consistent options; it had them, all right, and either ignored or discarded them. But, as we shall find, there is no need to excuse the visual system at all. Its fabrication of the devil's triangle is governed by elegant principles, and knowing these principles we can predict when its fabrications will be consistent or inconsistent.

And this, we shall find, is typical of your visual intelligence. Its nature is to construct, and to do so according to principles. Without exception, everything you see you construct: color, shading, texture, motion, shape, visual objects, and entire visual scenes. The three examples we just considered—the ripple, the magic square, and the devil's triangle—are simple demonstrations of your visual intelligence and its genius to construct.

But wait. If you construct all you see, then since you see this book, you construct it as well. And if that's so, then why should you buy it and why should I get royalties? What right have I to copyright your construction?

This question has more than passing interest to me as an author, and I shall have to raise a distinction to rescue my royalties. We use the phrase "what you see" in at least two ways. Sometimes we use it to mean "the way things look to you," "the way they visually appear to you," "the way you visually experience them."

Philosophers call this the *phenomenal* sense. Someone with delirium tremens may see, in the phenomenal sense, a pink elephant in the room, even though the rest of us do not. Someone normal may see, in the phenomenal sense, the devil's triangle, even though what is seen can't be built with wood. You see the depth and parts of the "ripple" in the phenomenal sense. You also see the edges and brightness of the magic square in the phenomenal sense. Photometers can't discern what you see in this sense of "see," and so they can't discern the magic square.

We also use the phrase "what you see" to mean roughly "what you interact with when you look." This is the *relational* sense. Someone with delirium tremens can, simultaneously, see a pink elephant in the phenomenal sense and fail to see a pink elephant in the relational sense—if there is in fact no pink elephant. A thing must exist to be seen in the relational sense. Suppose you are the only thing that exists (a strange idea called *solipsism*). Then you could never see anything else in the relational sense, since there would be nothing else to interact with. You might still, of course, continue to see in the phenomenal sense, since you might continue to have visual experiences.

So when I say that your visual intelligence constructs what you see, I mean "see" in the phenomenal sense: you construct your visual experience. When you look at this book, everything you see, i.e., everything you visually experience, is your construction: the thickness of the spine, the white color and rectangular shape of the pages, the black color and curved shapes of the letters—no less than the ripple, the magic square, and the devil's triangle.

But when you see this book there is also, I hope you will agree, something that you see relationally, something with which you interact. If so, that thing is something I helped to create (by typing at a computer terminal), and therefore I get to keep my royalty. Philosophical distinctions can indeed be of practical value!

This distinction, however, might cost you more than money, it might cost you worry. Just what are these things that we interact with when we see, and how do they relate to our visual experiences? Interesting issues lurk here, but we shall have to postpone them until later. But here, in brief, is a metaphor I find useful. The relation between what you see phenomenally and what you see relationally is like the relation between icons and software on a computer. When you use, say, that neat paint program or word processor on your PC, you interact with megabytes of software of such complexity that its creation took talented programmers many months of concerted effort. Fortunately for you, they made their software "user-friendly" so you don't need to know its grisly innards. They gave you colorful icons and clever graphical tools that make it easy to get your work done. As a result, you can be an expert user of that paint program without knowing how to write a program—indeed, without even knowing about or believing in programs. But every time you click an icon or drag a paintbrush you in fact interact with a complex unseen world of software (and hardware). The relation between icons and software is systematic but arbitrary; those icons could take many different forms and colors, as they often do from one paint program to the next, and still have the same function. Similarly, our visual experiences serve as our user-friendly icon interface with those things we relationally see (whatever they are). Experienced chairs, books, cars, trees, and stars are all icons of this interface.

We'll explore this "icon metaphor" in more detail later. For now, however, and for most of the book, we'll explore the genius of your visual intelligence to construct visual experiences—that is, to construct your icon interface.

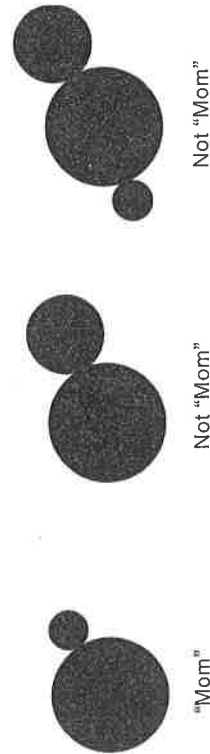
"The only difference between genius and stupidity," said an unknown wag, "is that genius is limited." This is precisely the finding of cognitive science. You are a genius at a few things, like vision and language, whether or not you have a high IQ. One must be severely retarded (or have a special handicap) before failing to see or talk. Your genius at vision, like your genius at language, is innate, safely wired into your brain under the influence of your genes. (However, the brain itself, with its neurons, is part of the icon interface. It is the icon we see when we peek inside skulls.)

But vision, unlike language, is a genius we share with many other animals. Of course, vision varies widely from species to species, and in many respects it's a mistake to think that vision in other species resembles vision in humans. To underline this point, the biologist Adrian Horridge prefers to call the vision of insects *semivision*. But the vision, or semivision, of other

species is impressive in its own right. Goldfish have color vision—in fact they have four color receptors, compared to our three—and “color constancy”: they can continue to find, say, green objects despite changes in color of the ambient light in their tank. Honeybees have color constancy and can see the magic square. They can also navigate using the sun as a compass, even if it’s hidden behind a cloud: they find it via the polarization of ultraviolet light from blue patches of sky. The fly uses visual motion to compute, in real time, how and when to land on a surface and how to alter its trajectory to intercept another fly. Day-old chicks discriminate spheres from pyramids, and peck preferentially at the spheres (most seeds are shaped like spheres, not pyramids). The praying mantis uses binocular vision to locate a fly in space and then, when the fly is at just the right distance, flicks out a foreleg to catch the fly in its tarsal-tibial joint. The mantis shrimp has ten color receptors, can find the range to a prey with just a single eye, and accurately stuns its prey with a quick strike of its raptorial appendage. Macaques monkeys see “structure from motion”: with just one eye open they can construct the three-dimensional (3D) shape of a moving object. And the story that holds for our visual genius holds, in every case, for theirs as well: vision is construction.

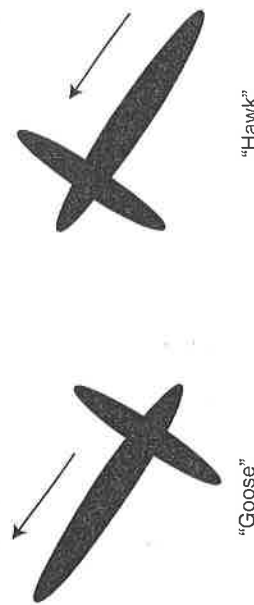
Of course some visual constructions display less genius than others. For newly hatched goslings, whose first priority is to find Mom and safety, the first big moving object they see becomes “Mom.” When Konrad Lorenz arranged to be that first big moving object, he instantly became “Mom” to several goslings, who faithfully followed him thereafter and, in adolescence, found him attractive as a possible mate.

The ethologist Niko Tinbergen found that for blackbird nestlings, “Mom” (or “parent”) can be as simple as two adjacent disks, one having a diameter about a third that of the other. The absolute size of the disks matters little, but if the ratio of their diameters deviates much from one third, or if there are extra disks around, then they are not “Mom”:



Hungry blackbird nestlings will gape to a cardboard copy of “Mom,” but not to copies of the other two figures.

Tinbergen also found that for chickens and ducks, a harmless “goose” can be a cross moving in the direction of its long end, and a feared “hawk” can be a cross moving in the direction of its short end:



A cardboard “hawk” flown overhead by mischievous ethologists sends chickens running for cover. A cardboard “goose” is ignored.

Jörg-Peter Ewert found that for the common toad *Bofu bofu*, a “prey” can be a stripe moving in the direction of its longer axis, and a “predator” can be a stripe moving along its shorter axis:



A cardboard “prey” moved around by other mischievous ethologists triggers the toad to orient, approach, fixate, snap, gulp, and wipe—only to find that cardboard just can’t satisfy like a juicy slug or a crunchy beetle. Gary Larson catches the humor of all this in a cartoon showing a frog stuck to the bottom of a jumbo jet by its outstretched tongue.

What’s so funny in each case is how easily the animal is duped. Simple figures trigger fantastic visual constructions. But as we laugh at these foibles we laugh at ourselves, for we too cannot help but create visual fantasies, as shown by the ripple, magic square, and devil’s triangle. Perhaps we aren’t taken in by our creations as badly as is the gosling. Yet, despite our better

judgment, a simple figure triggers us to construct a ripple, just as a large moving object triggers a gosling to construct "Mom." In this respect there is no difference in principle between us and goslings. There is a difference in practice: we're not duped by some visual figures that trigger visual fantasies in us. Likely that they aren't duped by some figures that trigger visual fantasies in us.

So we share with all sighted animals a genius to construct and, in consequence, a chance to err. This raises questions. When should we trust what we see? If the ripple and magic square are false constructs, what further falsehoods might we see? And if our "genius" to construct can mislead, then why not dispense with it and just see the world as it is?

The sobering fact is that we cannot dispense with construction. To construct is the essence of vision. Dispense with construction and you dispense with vision. Everything you experience by sight is your construction.